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Article

Optimal Level of Groundwater Charge to Promote Rainwater Usage for Irrigation in Rural Beijing

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Abstract: Since groundwater is diminishing rapidly in rural Beijing, rainwater harvesting for irrigation is being promoted. As the cost of pumping up groundwater is low, farmers have few incentives to use rainwater. To promote the consumption of rainwater, the Beijing Water Authority may in the future raise the cost of using groundwater by introducing a charge. Higher cost of groundwater will increase the consumption of rainwater, but can have a negative impact on farmers' incomes. This paper aims to study how to increase rainwater consumption without discouraging farming. The relation between the cost of groundwater and the consumption of rainwater has been studied by analyzing the elasticity of groundwater demand graphically. If the cost of groundwater is lower than the elasticity threshold, farmers lack incentives to use rainwater. If the cost of groundwater is higher than the threshold, rainwater consumption increases. The elasticity threshold of groundwater can move down following a change in the characteristics of rainwater harvesting systems. With linear programming analysis it has been found that increasing subsidies and enlarging the size of rainwater harvesting systems decreases the elasticity threshold of groundwater. This results in a proposal for a realistic charge for groundwater, affecting the consumption of rainwater but also taking into account the income of the farmers.

Keywords: irrigation water; elasticity of demand; groundwater charge; rainwater

1. Introduction

Groundwater contributes 75.6% of the irrigation water for agriculture in Beijing [1]. However, the groundwater in Beijing is diminishing significantly, caused by recurrent droughts and growing domestic and industrial water demand [2]. It is shown in Figure 1 that the groundwater level in Beijing has declined since the mid-1950s. In the rural areas of Beijing, mostly the minimum depth of a well to access the groundwater is 80 meters while 20 years ago farmers could get groundwater from a well of only 2 meters [3]. The lowering of the groundwater level could lessen water availability for agricultural irrigation and threaten the development of agricultural production [1,4-6]. It is necessary to provide other water resources to ensure sustainable agricultural development.

Figure 1. The change of groundwater water level in Beijing (Source: [7], masl means meters above sea level).

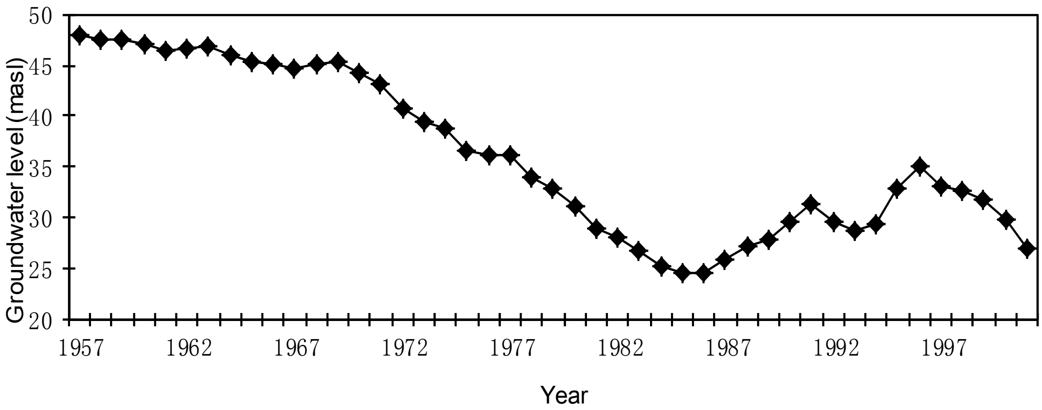
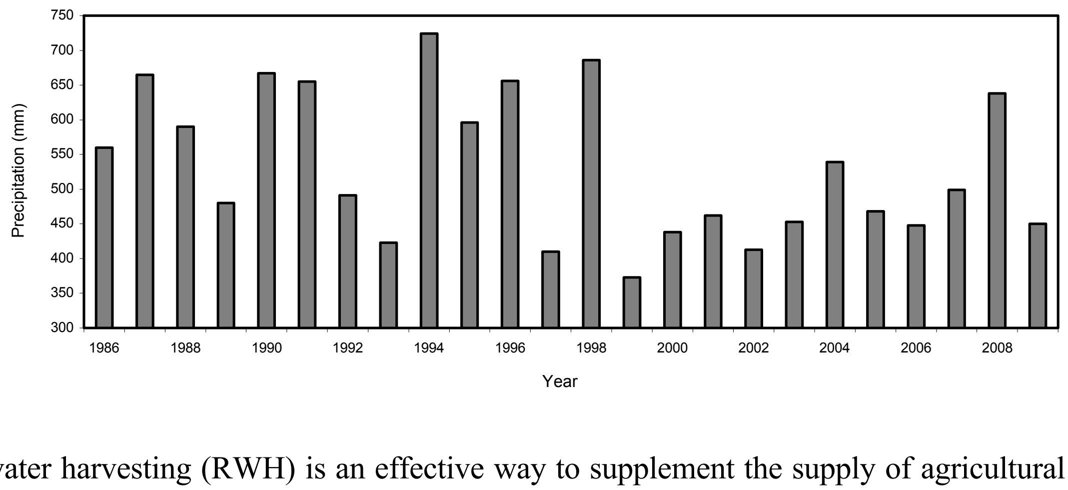
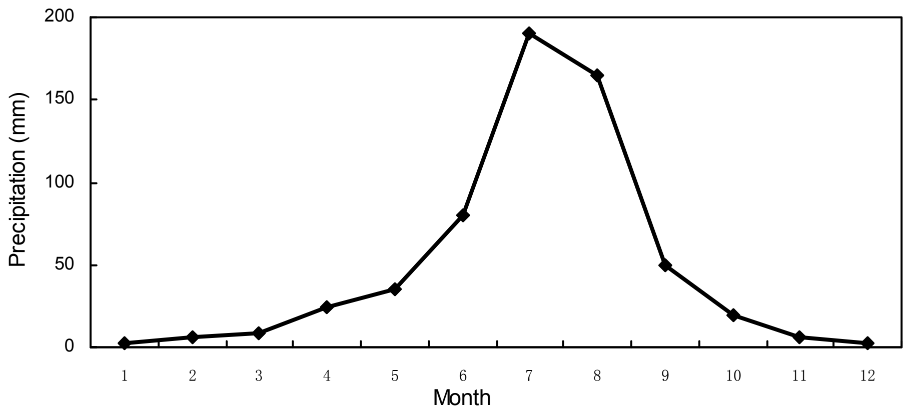


Figure 2. Precipitation rate in Beijing from 1986 to 2009 (Source: [2]).



Rainwater harvesting (RWH) is an effective way to supplement the supply of agricultural water [1]. Since 2006, hundreds of RWH systems have been constructed in the rural areas of Beijing. While these systems do not require a complex technology, they help to solve the problem of agricultural water scarcity. Basically the precipitation in Beijing can satisfy the requirement of agriculture irrigation. It is shown in Figure 2 that the average precipitation rate in Beijing stays at around 500 mm per year, although the precipitation rates in certain years are low. Eighty per cent of the precipitation in Beijing falls between April and September, based on the average values of 10 years data (Figure 3). According to interviews with managers of the rainwater harvesting projects, the rainwater harvesting plants usually operate from April to October because the precipitation is concentrated in this period. The rainwater harvesting plant is then idle in the winter time.

Figure 3. Average precipitation rate during one year in Beijing (Source: [2]).



From a technological and environmental point of view, rainwater is a suitable replacement for groundwater for agricultural irrigation [8-10]. However, from the financial point of view, using rainwater is not cheaper than using groundwater. Table 1 shows the average data from a farming household for using groundwater and the RWH system. There are 8 people living in the farming household who own a well and a RWH system. The initial investment of the well is 70,000 RMB, and the initial investment of a 50 m^3 storage tank is 27,000 RMB (Table 1). However, the unit investment and O&M costs (Operation and Maintenance) of using groundwater are lower than that of using rainwater, because the total water withdrawn from a well is much larger than that from a rainwater storage tank. The water withdrawn from a rainwater storage tank is only used to supplement agricultural irrigation, but the water withdrawn from a well is used for both people's needs and farming.

Table 1. Data for cost of groundwater and rainwater for an agricultural household.

Cost	**Using groundwater**	**Using rainwater (Storage capacity: 50 m^3)**
Initial investment (RMB)	70,000	27,000
The number of users	8	8
Total water withdraw (m^3/year)	30,000	250
Unit investment cost (RMB/m^3)	2.1	7
Unit O&M (Operation and Maintenance) cost	0.13	2.4

Due to the relatively low unit cost of using groundwater, farmers have few incentives to use rainwater. Only 30% of the constructed RWH systems in Beijing operate continually and the remaining systems are often run with interruptions or are not in use, according to interviews with officials of the Beijing Agro-Technical Extension Center.

The economic theory of substitution states that an increase in the price of particular goods will lead to an increase in demand for its substitute. It means that an increase in the cost of groundwater can raise the consumption of rainwater. If the cost of using groundwater is higher than using rainwater, farmers would prefer to reduce the consumption of groundwater while increasing the consumption of rainwater. Enforcing a levy on groundwater could be one method to increase the cost and restrict the consumption of groundwater [5]. According to the interviews with the officials, the Beijing Water Authority is going to raise the cost of using groundwater by collecting a charge on groundwater so as to restrict the groundwater consumption in the near future.

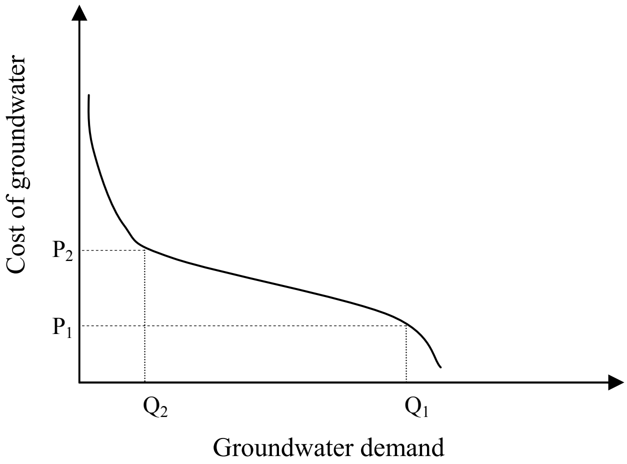
A higher cost of groundwater can effectively reduce groundwater consumption and motivate farmers to use rainwater. Meanwhile a higher cost of groundwater can affect the farmers' incomes negatively because it raises the cost of irrigation. It has been found by data from the Shanxi province of China that a tenfold increase in the price of water could reduce social welfare by 39 percent [11]. As farmers are the poorest people in Beijing, it seems unreasonable to increase the cost of irrigation [5,12,13]. From a policy perspective, the question is whether a groundwater charge can lead to an increase in rainwater consumption while not lowering farmers' incomes.

The objective of this study is to show how to increase the consumption of rainwater by charging for groundwater while not discouraging farming. This paper consists of two parts: graphical illustration and linear programming. In the graphical illustration, the relation between the cost of groundwater and the consumption of rainwater is studied graphically by analyzing the elasticity of groundwater. Many studies concerned with the price elasticity of irrigation water have found that when the price of water is lower than a threshold, irrigation water is price inelastic [13-16]. The cost of groundwater should be higher than the elasticity threshold so that the consumption of groundwater is sensitive to its cost. Hence increasing the cost of groundwater can raise the consumption of rainwater. If the elasticity threshold decreases, the cost of groundwater enabling the increase of rainwater consumption becomes lower. A low cost of groundwater would not discourage farming. Through linear programming, we try to find out how to decrease the elasticity threshold of groundwater, and then to determine a realistic charge of groundwater which affects not only the consumption of rainwater positively but also the income of the farmers as little as possible.

2. Graphical Illustration

It has been indicated in many studies that there are three thresholds of prices leading to different elasticity of groundwater demand change [13,16,17]. The groundwater can become inelastic at a too low price or at a too high price level. Only in the middle price range, is the groundwater price elastic. Figure 4 illustrates the relation between the cost of groundwater and its consumption. It is shown that when the cost is below a threshold value P_1, the consumption of groundwater is completely inelastic. Farmers react very little or not at all to an increase in groundwater cost. They maintain the existing groundwater demand. The cost of pumping up groundwater is too low to induce farmers to achieve water saving or to use other sources of water such as rainwater for agricultural irrigation. When the cost is higher than P_1, water consumption changes with different water costs (Figure 4). Because of a high elasticity, a small increase in the water cost can bring a large decrease in groundwater consumption. At this stage farmers would then use other water sources to supplement the irrigation water. The elasticity declines when the water cost is higher than P_2 (Figure 4). Given this situation, the consumption of groundwater is limited and farmers may decrease total water consumption through a series of water saving activities. They may change from water intensive crops to non-irrigated crops or crops requiring very little water.

Figure 4. The change in elasticity of groundwater in terms of different costs. (P means cost of groundwater; Q means groundwater demand).



It is assumed that there are only two water resources for agricultural irrigation: groundwater or rainwater, and that water demand for irrigation is fixed. As shown in Figure 2, basically the precipitation is at a constant value, which can satisfy the requirements of agricultural irrigation. Rainwater is a substitute for groundwater, which means when groundwater consumption increases, rainwater consumption will decrease, and vice versa. Figure 4 describes the relation between the cost of groundwater and its consumption. When the cost of groundwater increases, the consumption of groundwater will decrease and the consumption of rainwater will increase. Accordingly, based on Figure 4, the relation between the cost of groundwater and the consumption of rainwater can be estimated and is shown in Figure 5.

Figure 5. The relation between groundwater cost and rainwater demand. (V means rainwater demand).

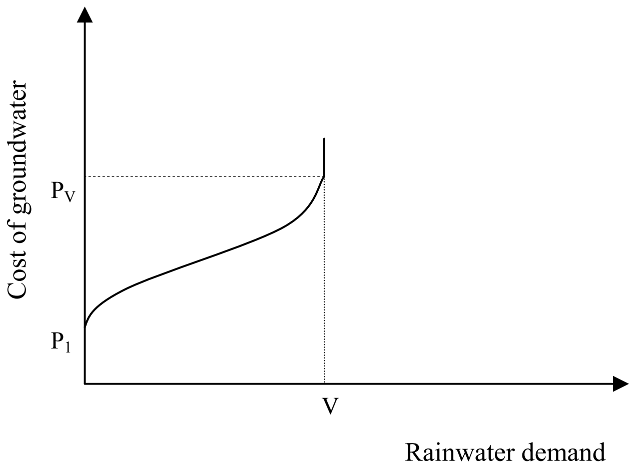
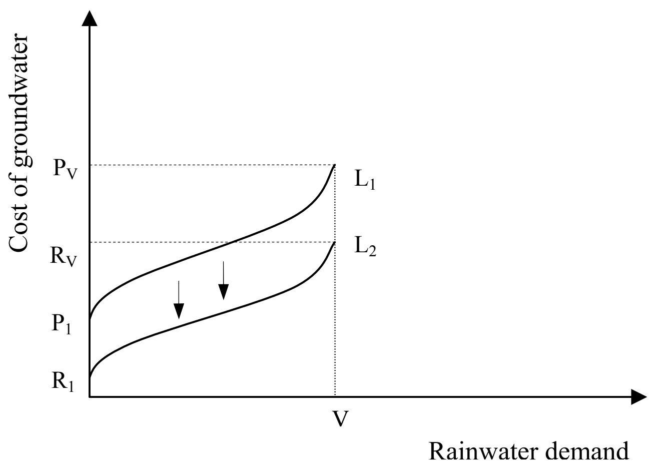


Figure 5 shows that when the cost of groundwater is lower than P_1, the consumption of rainwater tends to be zero. Farmers do not respond to the increasing cost of groundwater and continue to use it for irrigation. When the cost of groundwater is higher than the elasticity threshold P_1, the consumption of rainwater can rise with the increase in the cost of groundwater. Farmers respond to the increased groundwater cost by reducing the consumption of groundwater. To keep the same amount of water for irrigation, farmers would raise rainwater consumption to supplement water supply. The existing crop distribution does not change and total water consumption is the same. When the cost of groundwater increases to, or over P_v, rainwater consumption reaches its potential maximum harvesting amount V. At this stage, RWH systems are fully utilized, while little groundwater is extracted for agricultural irrigation due to its high cost. It should be noticed that the threshold value P_1 is the crucial value needed to improve the consumption of rainwater. As long as the cost of groundwater is higher than the threshold value P_1, the consumption of rainwater becomes sensitive to changes of the groundwater cost. This implies the precondition for increasing the consumption of rainwater is that the cost of groundwater is higher than the threshold value P_1.

If the prices for using groundwater or rainwater are changed, the line in Figure 5 can move up or down. Figure 6 illustrates the situation where rainwater demand is moving down. The curve line for rainwater demands moves from line 1 (L_1) to line 2 (L_2), because the threshold value decreases from P_1 to R_1. In the case of line 2 (L_2), the groundwater cost is above R_1, the consumption of rainwater becomes sensitive to a change of the cost of groundwater. To reach the same level of rainwater consumption, the cost of groundwater in the case of line 2 (L_2) can be lower than the cost of groundwater in the case of line 1(L_1). For example, to reach the potential maximum RWH amount V, the cost of groundwater in line 1 (L_1) should be P_v while the cost of groundwater in line 2 (L_2) is R_v which is smaller than P_v. As is mentioned previously, the condition for improving the consumption of rainwater is that the cost of groundwater is higher than the elasticity threshold value. If the elasticity threshold value decreases, the cost of groundwater does not need to be so high to increase the consumption of rainwater. A low cost of groundwater means the groundwater can be charged at a low price and farmers' incomes are not affected negatively. Thus the decline of the elasticity threshold value helps to improve the consumption of rainwater while charging the groundwater at a low level.

Figure 6. Movement of rainwater demand lines. (L means lines; R means cost of groundwater).



The curve line moving down according to the theory of substitution means that the cross elasticity increases. The responsiveness of the consumption of rainwater to the change of the cost of groundwater becomes higher. This can be taken in two ways: the change of characteristics of using groundwater, and the change in the characteristics of RWH. In this study, the characteristics of using groundwater do not change very much since the capacity of wells and the pumping costs tend to be quite similar. Hence the movement of curves represents the change in characteristics of RWH systems, such as the size of the RWH system, or the subsidies for initial investments.

The graphic analysis demonstrates the relation between the cost of groundwater and the consumption of rainwater. Rainwater consumption tends to be zero when the cost of groundwater is lower than the elasticity threshold. Once the cost of groundwater is larger than the elasticity threshold, farmers would increase the use of rainwater and decrease the consumption of groundwater. The threshold value is the important point to increase the consumption of rainwater. If the threshold value is low, a smaller groundwater cost is required to enable the increase of rainwater consumption. We also find that the threshold cost could decrease through a movement of the curve line. The movement of the curve line of rainwater can be achieved by changing the characteristics of the RWH system.

3. Linear Programming

We have used linear programming to find out which characteristics of RWH systems could lead to a change in the elasticity threshold of groundwater.

3.1. Data

The data source for the analysis is from interviews with managers of RWH systems in the rural areas of Beijing. Additionally, some relevant data are taken from the literature [3,18,19].

3.2. Linear Programming Model

From the point of view of farmers, the objective of linear programming is to obtain the maximum net profit. We assume that increasing water consumption in agricultural irrigation could increase the production of their crops. In this case, there are two alternative irrigation water sources: groundwater and rainwater. The objective function (Equation 1) illustrates that the net profit of production is determined by the consumptions of groundwater (q_1) and rainwater (q_2).

Objective function:

$$\text{Maximum } z = b(q_1 + q_2) - c_1 q_1 - c_2 q_2 \tag{1}$$

where, z is the net benefit of the project; b is the unit profit of crops (RMB/m^3). In terms of interviews with project managers, 80% of crops cultivated in the RWH systems in Beijing are as follows; cucumber, tomato, lettuce, and marrow, which all belong to vegetables. So only the production of vegetables concerns us in this study. The unique profit of crop incomes (b) in Beijing could be set at 6 RMB/m^3 [3]. q_1 is the consumption of groundwater (m^3); q_2 is the consumption of rainwater (m^3); c_1 is the unit cost of groundwater (RMB/m^3); c_2 is the unit cost of rainwater (RMB/m^3).

Constraints functions:

$$q_1 + q_2 \le Q \quad (2)$$

$$o \le q_2 \le V \quad (3)$$

Equation 2 and 3 illustrate the constraints on the consumption of groundwater (q_1) and rainwater (q_2). The total consumption from the two water sources can not be larger than the quantity required for irrigation (Q) (Equation 2). Moreover, the collected rainwater amount (q_2) is restricted by the potential maximum collected rainwater amount (V) (Equation 3).

The quantity required for irrigation (Q) relies on the water quantity required per unit irrigating area (L) and the area under irrigation (S), shown in Equation 4. L is 0.3 m^3/m^2, S is 1.17 million m^3 [3]. So the volume of the potential required irrigation water (Q) in the RWH systems under study can be calculated as 350,000 m^3.

$$Q = L \times S = 0.3 \times 1.17 \times 10^6 = 0.35 \times 10^6 m^3 \quad (4)$$

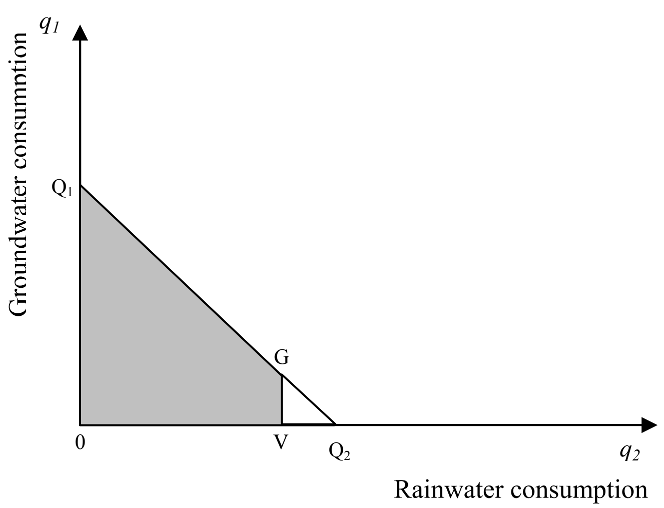
The potential maximum collected rainwater amount (V) depends on the volume of rain falling (k_p), the area where rainwater is collected (A), and the coefficient of effective RWH (K), shown in Equation 5. According to two studies, k_p equals 452 mm, A is 9.3 million m^2, K is 0.8 [3,18]. Hence the maximum collected rainwater volume (V) is calculated as 340,000 m^3 (Equation 5).

$$V = k_p \times A \times K / 1000 = 452 \times 9.3 \times 10^6 \times 0.8 \div 1000 = 0.34 \times 10^6 m^3 \quad (5)$$

3.3. Graphical Solution of Linear Programming

In terms of the constraints functions, we can determine the region of feasible solutions. As $q_1 + q_2 \le Q$, the possible values of q_1 and q_2 lie below the line of Q_1Q_2. But q_2 is smaller than V. Determination of Equation 4 and 6 illustrates that the V value is smaller than the Q value. So the feasible values of q_1 and q_2 are limited to the dark area of Figure 7. The optimal solution will be a point on the frontier of the region of all feasible solution.

Figure 7. Region of feasible solutions. (Q means quantity required for irrigation; q_1 means consumption of groundwater; q_2 means consumption of rainwater; G means intersection point).



The objective function can be presented graphically by isoprofit lines. In this case, the isoprofit line is denoted by line *AB*, shown in Figures 8, 9 and 10. The optimal solution can be found by the point of tangency of the frontier of the region of feasible solutions to the highest possible isoprofit curve [20]. So the optimal solution depends on the slope of the isoprofit lines.

In this study, the objective function is $z = b(q_1 + q_2) - c_1q_1 - c_2q_2$, which can be changed to $q_1 = \frac{z}{b-c_1} - \frac{b-c_2}{b-c_1} \times q_2$. Thus the slope of the isoprofit line is $\frac{b-c_2}{b-c_1}$. The possible frontier of the region of feasible solutions includes two points: Q_1 and G and one line: Q_1G. As the line of Q_1G is the boundary line of the constraint: $q_1 + q_2 \le Q$, its slope equals 1. Following the change of the slope of the isoprofit lines, three kinds of optimal solutions could appear.

Figure 8. Optimal solution 1 (the isoprofit slope <1).

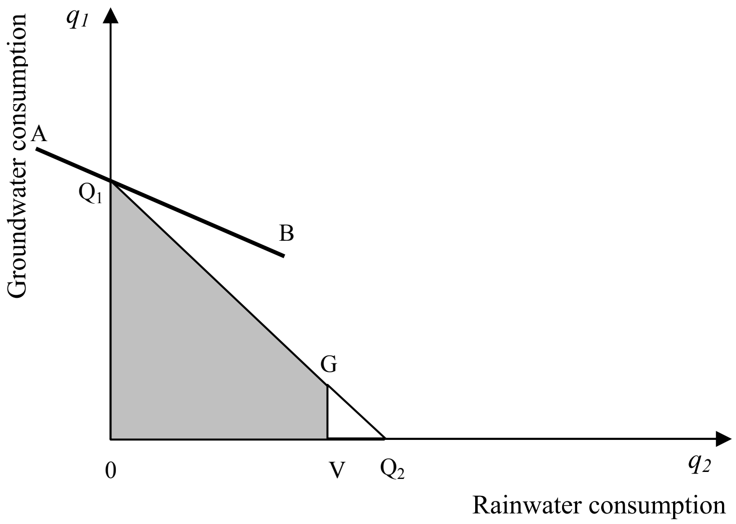


Figure 9. Optimal solution 2 (the isoprofit slope = 1).

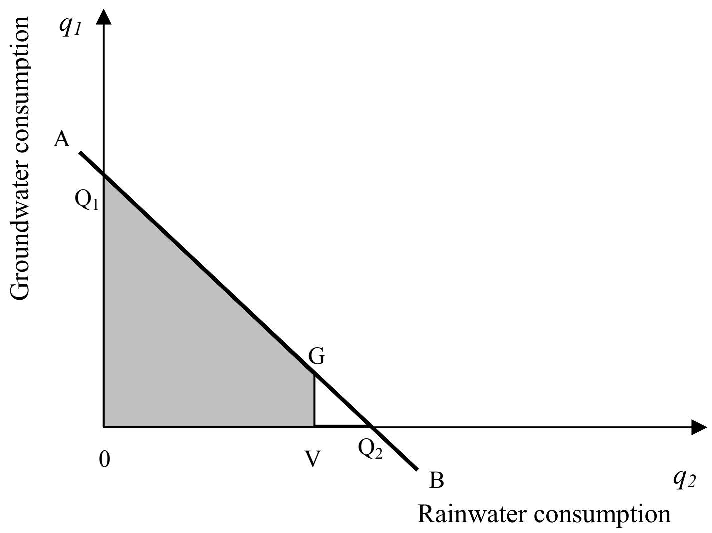
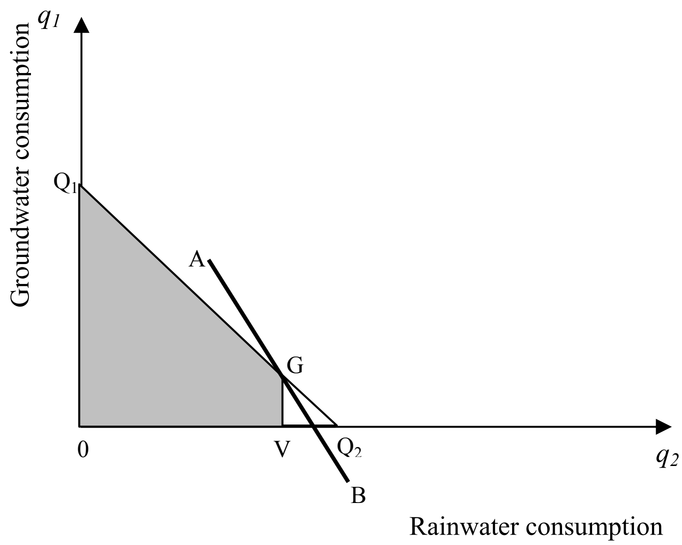


Figure 10. Optimal solution 3 (the isoprofit slope >1).



Firstly, if the slope of the isoprofit lines is smaller than 1, the point of tangency is the point of Q_1, shown in Figure 8. At the point of Q_1, $q_1 = Q$ and $q_2 = 0$, which means that the consumption of rainwater is zero while the consumption of groundwater reaches its maximum. In this situation, $\frac{b-c_2}{b-c_1} < 1$, namely $c_2 > c_1$. So when the unit cost of groundwater is smaller than the unit cost of rainwater, the consumption of rainwater is zero.

Secondly, if the slope of the isoprofit lines equals 1, all the points in the line of Q_1G could be the optimal solutions, shown in Figure 9. Given this situation, the consumption of rainwater could range from 0 to *V*. The slope of the isoprofit lines equals 1, which means $\frac{b-c_2}{b-c_1} = 1$, namely $c_1 = c_2$. So when the cost of groundwater and the cost of rainwater are the same, farmers may start to use rainwater.

Thirdly, if the slope of the isoprofit lines is larger than 1, the point of tangency is the point of *G*, shown in Figure 10. At the point of *G*, the consumption of rainwater is *V* and the consumption of groundwater is (Q-V). In this situation, $\frac{b-c_2}{b-c_1} > 1$, namely $c_2 < c_1$. So when the unit cost of groundwater is larger than that of rainwater, farmers would decrease the consumption of groundwater and increase the consumption of rainwater.

It can be concluded that different values of the cost of groundwater and rainwater will lead to different optimal solutions for the consumption of both water sources. Since zero consumption of rainwater is not suitable to the objective of increasing rainwater consumption, the first optimal solution is not considered in this study. The second optimal solution shows that when the cost of groundwater equals the cost of rainwater, the consumption of rainwater will increase. When the cost of groundwater is larger than the cost of rainwater, the rainwater consumption reaches the maximum potential value, shown in the third optimal solution.

Therefore, only when the cost of groundwater equals or is larger than the cost of rainwater, can the groundwater consumption start to decrease and the rainwater consumption begin to increase.

Otherwise, the increasing cost of groundwater can not restrict groundwater consumption and improve rainwater consumption. In the linear programming analysis, the unit cost of rainwater could be regarded as the elasticity threshold of groundwater.

4. Decreasing the Threshold Value of Groundwater

The graphical study in Section 2 illustrates that there is a threshold value for the groundwater cost which determines the increasing consumption of rainwater. It also shows that the threshold value could be decreased by changing the characteristics of the RWH system. The optimal solution in Section 3 shows that when groundwater cost (c_1) is larger than rainwater cost (c_2), farmers begin to increase rainwater consumption. It implies that the unit cost of rainwater could be regarded as the threshold value for the groundwater. In this section, we will discuss how to decrease the threshold value, namely the unit cost of rainwater by a change in the characteristics of the RWH system.

Equation 6 shows that the unit cost of rainwater includes the initial investments (c_I) and the operation and maintenance cost (c_o), which are affected by two major factors: the size of RWH systems and the subsidies. In terms of the economies of scale, the large systems have a small unit initial capital input, while the small systems have a large unit capital input. The unit capital input is the total capital input divided by the capacity of the RWH plant. In the same way, the unit operation and maintenance cost of the large systems is lower than that of the small systems. Additionally subsidies could effectively decrease the initial expenditures made by farmers so as to reduce the cost of using RWH systems. It could be deduced that enlarging the size of RWH and increasing subsidies may decrease the threshold value of groundwater.

$$c_2 = c_I + c_o \tag{6}$$

$$c_I = u_I\left(\frac{1-r_1}{L} + \frac{r_2}{L}\right) \tag{7}$$

The calculation of the unit initial cost of RWH is shown in Equation 7. u_I is unit capital investment; r_1 is residential radio of RWH system; r_2 is replacement ratio of RWH system; L is life time of system. According to the literature, r_1 is 4%, r_2 is 0.25% and L is 20 years [19].

There are three sizes of RWH systems according to the interviews: 50 m^3, 450 m^3 and 1,300 m^3 and two kinds of subsidies: 25% and 75% of the initial investment cost. For the purpose of making a comparative analysis, data are used concerning different sizes of RWH systems and different levels of subsidy. Tables 2 and 3 provide the initial investments and operation and maintenance cost for three sizes of RWH systems; the data were obtained from interviews with project managers. Normally subsidies are only provided for initial investments and no subsidies are given for operation and maintenance cost. For the calculation, we assume the number of users of a small RWH system (50 m^3) is 8 persons, for a medium system (450 m^3) 80 persons, and for a large system (1,300 m^3) 150 persons (Table 2). It is shown in Table 3 that the operation and maintenance cost (c_o) of each size of system is the same but the capital investment (u_I) decreases, given the situation of providing subsidies.

Table 2. The parameters for different sizes of rainwater systems (RMB/m^3).

Size (m^3)	O&M cost (c_o)	Capital investment (u_I)	Population of user
50	2.41	140	8
450	0.51	92	80
1300	0.41	77	150

Table 3. Data for different sizes of rainwater systems with subsidies (RMB/m^3).

Sizes and subsidies	O&M cost (c_o)	Capital investment (u_I)
50 m^3		
25% of investments	2.41	105
75% of investments	2.41	35
450 m^3		
25% of investments	0.51	69
75% of investments	0.51	23
1300 m^3		
25% of investments	0.41	58
75% of investments	0.41	19

After putting the data of Tables 2 and 3 into Equation 6 and 7, the rainwater cost, namely the threshold value can be calculated (Table 4). We find that the threshold values of groundwater decrease with the increase of the size of RWH system. For example, given the situation of no subsidies, the threshold value is 9.11 RMB/m^3 if the size of rainwater system is 50 m^3; while the threshold value decreases to 4.91 RMB/m^3 if the size is enlarged to 450 m^3. Subsequently, the threshold reduces to 4.11 RMB/m^3 if the size becomes 1,300 m^3. Moreover, an increase in the subsidies on initial investments of RWH could decrease the value of the threshold of groundwater. For example, provided the size is 450 m^3, the threshold value could decrease from 3.81 to 1.61 RMB/m^3 when the subsidies increase from 25% to 75% (Table 4). The data shown in Table 4 proves that enlarging the size of RWH and increasing subsides can decrease the threshold value of groundwater.

Table 4. Threshold values of groundwater for different sizes and subsidy levels for RWH systems.

Size of RWH system & subsidy	Threshold of groundwater (RMB/m^3)
50 m^3	
0 subsidies	9.11
25% of investments	7.41
75% of investments	4.11
450 m^3	
0 subsidies	4.91
25% of investments	3.81
75% of investments	1.61
1300 m^3	
0 subsidies	4.11
25% of investments	3.21
75% of investments	1.31

The decline in the threshold of groundwater means that the charge on groundwater enabling the increase of rainwater consumption could be lower. Table 4 indicates the data of threshold value, namely rainwater cost (c_2). The optimal solution shows the unit cost of groundwater should be bigger than the unit cost of rainwater ($c_1 > c_2$).We can then get the realistic groundwater charges value by determining Equation 8.

$$c_1 = c_w + c_e + p_u \tag{8}$$

Equation 8 shows that the cost of using groundwater consists of three parts: unit cost of initial investment on a well (c_w), unit pumping cost (c_e) and water charge (p_u). As mentioned previously, the initial investment on a new well is around 70,000 RMB. The number of users for different sizes of RWH is assumed, so we can estimate that the number of wells for 8 people who use 50 m^3 RWH system is 1, for 80 people who use 450 m^3 RWH system is 2, and for 150 people who use 1300 m^3 RWH system is 3. The pumping cost (c_e) depends on the depth of a well which is generally 80 meters. According to the interviews with project managers, the average unit energy cost of pumping groundwater (c_e) is 0.13 RMB/m^3. It is assumed that the groundwater level stops decreasing. So the unit energy cost of pumping remains a fixed value.

It is shown in Table 5 that the realistic groundwater charge decreases when the size of the RWH systems becomes larger. For example, given the situation of no subsidies, the realistic groundwater charge should be larger than 6.88 RMB/m^3 if the size of rainwater system is 50 m^3; while the realistic groundwater charge should be larger than only 3.98 RMB/m^3 if the size of rainwater system is 1,300 m^3. Moreover, it is shown in Table 5 that if the subsidies for RWH systems increase, the groundwater charge could be less. For the rainwater system of 450 m^3 with 25% of initial investments subsidized, the realistic groundwater charge should be larger than 3.28 RMB/m^3 to achieve an increasing consumption of rainwater. But if with the same size the subsidies increase to 75%, the groundwater charge has only to be larger than 1.08 RMB/m^3 (Table 5).

Table 5. Groundwater charge corresponding to different sizes and subsidies for RWH systems.

Size of system & subsidy	Groundwater charge (RMB/m^3)
50 m^3	
0 subsidies	> 6.88
25% of investments	> 5.18
75% of investments	> 1.88
450 m^3	
0 subsidies	> 4.38
25% of investments	> 3.28
75% of investments	> 1.08
1300 m^3	
0 subsidies	> 3.68
25% of investments	> 2.78
75% of investments	> 0.88

Therefore, enlarging the size and increasing subsidies of RWH systems could help to decrease the threshold value. The decline of the threshold value implies that the groundwater charge enabling an increase of rainwater consumption is lower. So, in order to increase rainwater consumption, we can promote the construction of larger RWH storage tanks and increase the subsidies for RWH systems. Meanwhile groundwater should be charged at a low level so as to not discourage farming.

5. Conclusions

This paper uses graphic illustration and linear programming to study how to achieve an increase in the consumption of rainwater by charging for groundwater, while not discouraging farming. The graphical illustration provides the elasticity threshold for a groundwater charge. If the groundwater cost is lower than the threshold, farmers would have few incentives to change their water source from groundwater to rainwater. If the groundwater cost is higher than the threshold, the consumption of rainwater increases. The graphical illustration also shows that the elasticity threshold of groundwater could move down following changes in the characteristics of RWH systems. The linear programming illustrates that increasing subsidies and enlarging the size of RWH systems can decrease the elasticity threshold of groundwater. Decreasing the elasticity threshold of groundwater implies that the cost of groundwater enabling the increase of rainwater consumption becomes lower. Hence a realistic groundwater charge can be determined.

The price mechanism alone is not enough to increase rainwater consumption. Increasing the groundwater price may raise the farmers' incentives to use rainwater, but it also could lead to a significant decrease in farmers' income. It is important to reach the balance of effectively increasing rainwater demand while keeping an eye on farmers' benefits. The outcome of this paper indicates that increasing subsidies for initial investments and promoting larger size RWH systems can both help to achieve this delicate balance.

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